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Original Article

Concentrations and solubility of selected trace metals in leaf and bagged black teas commercialized in Poland

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ABSTRACT

The objective of this study was to determine the concentrations of heavy metals in bagged and leaf black teas of the same brand and evaluate the percentage transfer of metals to tea infusion to assess the consumer exposure. Ten leaf black teas and 10 bagged black teas of the same brand available in Poland were analyzed for Zn, Mn, Cd, Pb, Ni, Co, Cr, Al, and Fe concentrations both in dry material and their infusion. The bagged teas contained higher amounts of Pb, Mn, Fe, Ni, Al, and Cr compared with leaf teas of the same brand, whereas the infusions of bagged tea contained higher levels of Mn, Ni, Al, and Cr compared with leaf tea infusions. Generally, the most abundant trace metals in both types of tea were Al and Mn. There was a wide variation in percentage transfer of elements from the dry tea materials to the infusions. The solubility of Ni and Mn was the highest, whereas Fe was insoluble and only a small portion of this metal content may leach into infusion. With respect to the acceptable daily intake of metals, the infusions of both bagged and leaf teas analyzed were found to be safe for human consumption.

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1. Introduction

Tea is one of the most popular beverages all over the world. About 18–20 billion cups of tea are consumed daily worldwide; therefore, there is an economic and social interest in tea [1–3]. Consumption of tea in Poland is about 0.7–1.5 kg/person per year. It is the second (after water) most consumed beverage in Poland [4]. The health benefits of tea have been well documented [2,5]. However, consuming tea may provide also a significant contribution for intake and accumulation of trace metals in the human body, which was not fully studied. Although tea is considered a healthy beverage, we should keep in mind its potentially toxic effects, which have been neglected in the past [1].

Tea is made from dried leaves of a shrub, *Camellia sinensis* [6]. Production of black tea involves plucking, indoor withering, leaf disruption, fermentation, and drying [7]. The last

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stage involves sorting the leaves into grades according to their sizes (whole leaf, broken leaf, fannings, and dust). Whole leaves are of the highest quality, followed by broken leaves, fannings, and dusts. Whole leaf teas have a coarser texture than bagged ones and are considered the most valuable. Broken tea leaves are usually sold as medium-grade loose teas or, together with fannings and dusts, can be manufactured for use in tea bags [8]. The final composition, aroma, color, and taste of tea depend on the processing stages and degree of fermentation [9]. However, only a few studies have focused on the comparison of concentrations in different types of teas of the same brand.

The leaves of *Camelia sinensis* are a source of mineral elements such as zinc, manganese, iron, copper, magnesium, titanium, aluminum, strontium, bromine, sodium, potassium, phosphorous, iodine, and fluorine. The tea infusion contains small amounts of proteins, vitamins, and carbohydrates but may be a source of metals and metal binding polyphenols [2,10]. The regular consumption of tea may contribute to the daily requirements of some elements. Some metals found in tea (e.g., Fe, Mn, Zn) are components of important enzymes or participants in a number of physiological processes so they are considered essential for the proper functioning of the human body [10–12]. However, some of the other elements are undesirable or toxic to human health, such as As, Cr, Cd, Co, Ni, and Pb [10,13–15]. Previous studies showed that tea can be rich in trace metals classified as human carcinogens by the International Agency for Research on Cancer. These are, in particular, Cd, Co, Cr, and Ni [13,16–18]. Determination of trace metals in tea is important for two reasons: to evaluate their nutritional value and to guard against any probable harmful effects they may cause to human consumers [3,6,10].

Tea infusion can be a reliable dietary source of major and trace elements because, while brewing, elements included in tea leaves are differentially extracted into infusions. The amount of elements that can get into the human body depends on the following parameters: total content in dry tea, characteristics of water used for brewing, fraction of the total content extracted to the infusion, and bioavailability of the element from the beverage [6,19].

In the present study, it has been hypothesized that bagged black tea contains higher amounts of trace metals than leaf tea of the same brand and that the trace metal content in infusion made from bagged tea is higher than made from leaf tea. Therefore, the type of tea chosen by consumers is important in view of intake of toxic metals. To verify the hypothesis, concentrations of Zn, Mn, Cd, Pb, Ni, Co, Cr, Al, and Fe in black tea samples and in tea infusions were determined and compared. The objective of the study was to evaluate the percentage transfer of the elements tested to the infusion and determine the concentrations of trace metals available in bagged tea and leaf black tea of the same brand.

2. Materials and methods

Ten commercial leaf black teas and 10 commercial bagged teas of the same brand from well-known tea trading companies were purchased at local stores in Wrocław, Poland, in March 2013 (Table 1). The procedure described by Dambiec et al [20] was followed for the preparation of samples for analysis of metal concentrations in dry teas and tea infusions.

Prior to analysis, five infusion bags were randomly selected from each box of tea, and their contents were mixed. Samples of both bagged and leaf teas were dried at 50°C to constant weight and ground into fine powder in a laboratory mill IKA Labortechnik M20 (Staufen, Germany) to obtain a representative sample.

Table 1 – Description of studied brands of commercially purchased black teas.

Tea type	Tea sample	Name	Producer/importer	Origin	Steeping time (min)[a]
Bagged tea	1	Tetley classic	TATA Global Beverages Polska Sp. Z o.o., Poland	Indefinite origins	3
	2	Lloyd tea ceylon	Mokate S.A., Poland	Sri Lanka	4–5
	3	Dilmah ceylon gold	MJF Holdings Ltd., Sri Lanka	Sri Lanka	3–5
	4	Sir Roger yunnan	Roger Sp. z o.o., Poland	China	3–5
	5	Posti yunnan	Posti S.A., Poland	China	4–6
	6	Lipton yellow label tea	Unilever Polska Sp. z o.o., Poland	Indefinite origins	1–2
	7	Ahmad tea English No.1	Ahmad tea Ltd	Sri Lanka	
	8	Posti ceylon	PH-W “POSTI” S.A., Poland	Sri Lanka	4–6
	9	Oskar black tea bags yunnan style	Oskar International Trading Sp. Z o.o., Poland	China	—
	10	Irving daily classic	Amber Spark S.A., Poland	Indefinite origins	2–3
Leaf tea	11	Tetley classic	TATA Global Beverages Polska Sp. Z o.o., Poland	Indefinite origins	3
	12	Lloyd ceylon	Mokate S.A., Poland	Sri Lanka	5–7
	13	Dilmah ceylon gold	MJF Holdings Ltd., Sri Lanka	Sri Lanka	3–5
	14	Sir Roger yunnan	Roger Sp. z o.o., Poland	China	3–5
	15	Posti yunnan	Posti S.A., Poland	China	4–6
	16	Lipton yellow label tea	Unilever Polska Sp. z o.o., Poland	Indefinite origins	3–5
	17	Ahmad tea English No.1	Ahmad Tea Ltd., UK	Sri Lanka	4–6
	18	Posti ceylon	PH-W “POSTI” S.A., Poland	Sri Lanka	4–6
	19	Oskar gold yunnan black tea	Oskar International Trading Sp. z o.o., Poland	China	3–5
	20	Irving daily superior	Amber Spark S.A., Poland	India	3–5

[a] According to the instructions given by tradesmen.

2.1. Mineral analysis of dry tea material

In order to determine the total metal concentrations in dry tea material, homogenized samples (1 g) were digested in an open system with concentrated nitric acid and hydrogen peroxide. During the process, the temperature was raised to 95°C until the evolution of nitrous oxide gas stopped and the digest became clear. Subsequently, the digests were cooled and diluted to 100 cm^3 with deionized water in volumetric flasks and then filtered. Aluminum, Fe, Mn, and Zn concentrations were determined using Flame Atomic Absorption Spectrometry (FAAS), and Cd, Co, Pb, Cr, and Ni using Electrothermal Atomic Absorption Spectrometry (ET AAS) with an AVANTA PM Atomic Absorption Spectrophotometer from GBC Scientific Equipment (Hampshire, IL, USA). The operating conditions of the atomic absorption spectrometer are summarized in Table 2.

2.2. Mineral analysis of infusion liquid

Tea infusions were prepared by adding 80 cm^3 of boiling deionized water to 2.0 g of broken tea leaves (to represent the typical quantity consumed by tea drinkers). The tea infusion was mixed using a glass rod to ensure adequate wetting, then covered and allowed to steep for 5 minutes (according to the tea industry's recommended brew time). Next, the solution was filtered, cooled, and diluted with deionized water to 100 cm^3 in volumetric flask. Aluminum, Fe, Mn, Zn, Cd, Co, Pb, Cr, and Ni concentrations were determined using the above-described methods. Concentrations of Cd and Co in some tea infusions were below the detection limit of 0.006 and 0.066 mg/kg, respectively.

2.3. Quality control

Prior to use, all plastic and laboratory glassware were cleaned by rinsing with 10% HCl and then distilled water. Deionized water was used throughout the experiment for the preparation of all solutions. All chemicals and reagents used were of analytical grade supplied by Chempur (Piekary Śląskie, Poland). Blank samples were prepared by following the same procedures but without tea leaf or infusion. The results were calculated on a dry weight basis. The accuracy of the methods used was compared to the results of an interlaboratory study through digesting and analyzing the reference material, Bush Branches and Leaves, NCS DC73348 LGC standards (China National Analysis Center for Iron & Steel, Beijing, China) (Table 3). The analytical methods were also validated by limit of detection, limit of quantification, precision, and linearity (Table 3). For all elements, calibration was performed using standards containing the same matrix as the samples and subjected to the same procedure. Atomic absorption standard solutions of Al, Mn, Zn, Cd, Cr, Co, Ni, and Fe at a concentration of 1.000 mg/L were obtained from Sigma-Aldrich Ltd. (Poznań, Poland).

2.4. Data analysis

The Mann–Whitney *U* test was used to determine the differences between bagged and leaf teas of the same brand as well as between their infusion in respect of element concentrations and in respect of the percentage extraction of each element from the dry tea to the infusion [21]. The normality of the analyzed features was checked with Shapiro–Wilk's test [22]. Statistical confidence was set at $\alpha = 0.05$. The percentage extraction of each element from the dry tea to the infusion was determined using the following ratios: element concentration in tea infusion/element concentration in blended tea leaves (100%). All statistical calculations were carried out using CSS-StatisticaStatsoft (StatSoft Polska Ltd., Kraków, Poland; www.statsoft.com) [23].

3. Results and discussion

The ranges of total element contents for individual dry tea samples and element concentrations in tea infusions examined in the present study are summarized in Tables 4 and 5, respectively.

The bagged and leaf teas of the same brand differed significantly in respect of Pb, Mn, Fe, Ni, Al, and Cr contents (Mann–Whitney *U* test, $\alpha = 0.05$). The trace metal concentrations of the bagged teas were significantly higher than the values for the leaf teas of the same brand. It may be associated with different production processes and the quality of the tea. The tea bags often contain older leaves and low-cost tea materials [24,25]. According to other research groups [6,13,26,27], the total Al, Mn, and Pb content increases with increasing age of tea plants, and it is probable that old leaves were the major contributors to the higher Al, Mn, and Pb concentrations in bagged tea in relation to leaf tea. The high content of Cr is caused by leaching into the tea material mainly through the crush, tear, and curl (CTC) process during the manufacturing of black bagged tea. The rollers used in CTC tea manufacturing are made of stainless steel containing Cr (17% w/w) [28]. Kumar et al [29] also suggest that a widely different elemental content of different types of tea (e.g., granular tea leaves, powder, and tea bags) is associated with the different processing methodology. This is of importance to the consumer, as the use of bagged teas is very popular worldwide [7].

The bagged and leaf teas only differed slightly in respect of mean element concentration sequences, which were as follows: Mn > Al > Fe > Zn > Co > Ni > Cr > Pb > Cd for bagged tea

Table 2 – The operating conditions of atomic absorption spectrometer.

	Al	Cd	Co	Cr	Fe	Pb	Mn	Ni	Zn
Wavelength (nm)	309.3	228.8	357.9	240.7	248.3	217.0	279.5	232.0	213.9
Slit width (nm)	0.5	0.5	0.2	0.2	0.2	1.0	0.2	0.2	0.5
Lamp currents (mA)	10.0	3.0	6.0	6.0	7.0	5.0	5.0	4.0	5.0
Flame type	Air–C_2H_2				Air–C_2H_2		Air–C_2H_2		Air–C_2H_2

Table 3 – Validation of analytical method.

Figures of merit	Al	Cd	Co	Cr	Fe	Pb	Mn	Ni	Zn
LOD	0.027 (μg/mL)	0.06 (μg/L)	0. 66 (μg/L)	0.19 (μg/L)	0.033 (μg/mL)	0.76 (μg/L)	0.044 (μg/mL)	0.59 (μg/L)	0.009 (μg/mL)
LOQ	0.081 (μg/mL)	0.18 (μg/L)	1.25 (μg/L)	0.58 (μg/L)	0.10 (μg/mL)	2.29 (μg/L)	0.13 (μg/mL)	1.78 (μg/L)	0.027 (μg/mL)
Accuracy (%)	101.87	92.86	97.44	101.74	104.41	94.79	96.76	101.76	102.66
Precision (%)	2.51	2.73	4.31	3.51	1.10	4.79	0.86	2.96	1.51
Linearity	$y = 2182x - 153$	$y = 30.1x - 0.35$	$y = 183x - 1.85$	$y = 47.9x - 0.22$	$y = 13.5x - 0.20$	$y = 28.3x - 0.31$	$y = 13.7x - 0.23$	$y = 210x - 1.84$	$y = 3.26x - 0.024$
Correlation coefficient (*R*)	0.999	0.999	0.999	0.999	0.996	0.999	0.998	0.999	0.998

LOD = limit of detection; LOQ = limit of quantification.

samples and Mn > Al > Fe > Co > Zn > Ni > Cr > Pb > Cd for leaf tea samples. This is similar to the results of Szymczycha-Madeja et al [6], who stated that tea is rich in Fe and Zn but contains very low levels of toxic metals (i.e., Cd and Pb). In the present research, the most abundant elements in the leaf and bagged tea samples were Mn and Al. The high content of Al is in accordance with the results of Mehra and Baker [7], who reported the accumulation of large quantities of Al by tea plants. The increase in Al content in black tea can also be connected to the frying of leaves aimed to change the composition and stop the fermentation process that is performed using pans made of Al–Cu alloys [30].

Tea infusions differed from teas with respect to element concentration sequences, which were as follows: Al > Mn > Zn > Fe > Ni > Cr > Pb for infusions from bagged teas and Al > Mn > Zn > Fe > Ni > Cr > Co > Pb for infusion from leaf teas. The infusions of bagged and leaf teas differed significantly in respect of Al, Cr, Mn, and Ni (Mann–Whitney *U* test, $\alpha = 0.05$). A higher average content of these elements in the infusions made with bagged tea, compared with infusions made of leaf tea, was observed. It can be associated with a high content of some of these elements in dry tea due to the lower quality of bagged teas. Moreover, the whole leaves are manufactured following the orthodox process, resulting in less cellular damage compared with the CTC process often used for teabag leaves [31]. Thus, the tea leaves in the bags are crushed more easily into small pieces, which may lead to better extractability of the elements [8,31], especially Ni and Al. The percentage extraction of these elements was significantly higher in bagged teas than in leaf teas (Mann–Whitney *U* test, $\alpha = 0.05$).

The amount of trace elements extracted into the tea infusions depends principally on whether the compound is strongly bound to the matrix or more soluble in the solution used [32]. Some of the trace metals, such as Cd and Co, were poorly soluble; therefore, the mean concentrations of these metals in infusions were below the detection limit. These results are in agreement with AL-Oud [33], who also noted very low solubility of these elements. Iron and lead can be classified as poorly extractable (<20%), which means that concentrations in infusions are low or even undetectable [6]. The calculated extraction efficiency of Pb was 10% for bagged teas and 13.1% for leaf teas. The percentage transfer of Fe was especially low and amounted, on average, to 1.4% for bagged tea and 2.4% for leaf tea. Street et al [34] reported a similar percentage transfer of this metal (0.94–4.04%). Manganese, Zn, Cr, and Al extraction efficiencies were in the range of 20–50%, so according to Szymczycha-Madeja et al [6], they can be regarded as moderately extractable elements. The percentage extraction of Ni was the highest for both bagged and leaf teas and amounted to 80.1% and 56.9%, respectively. These values are in accordance with the report of Szymczycha-Madeja et al [6], who classified Ni as highly extractable (>55%).

The calculated daily intakes of the studied metals showed that the tea infusion could contribute toward daily intake of some metals (Table 6). In the case of bagged tea, the calculated daily intake of Al, Cr, Mn, and Ni was on average about two times greater than that in leaf tea. The contribution of tea from drinking three cups daily to total exposure only in the case of Al and Mn is substantial. The values of calculated daily

Table 4 – Mean concentration of trace metals in dry tea material (each value is the mean of three samples).

Tea type	Tea sample	Mn	Zn	Cd	Pb	Ni	Co	Cr	Al	Fe
Bagged tea	1	941	30.5	0.0069	1.51	6.20	0.09	7.10	761	239
	2	738	29.6	0.035	1.31	3.25	0.18	3.19	584	328
	3	313	30.4	0.042	1.07	2.72	ND	1.20	407	165
	4	963	28.6	0.025	1.38	3.75	0.18	3.31	567	305
	5	1169	27.5	0.050	2.31	4.57	0.35	3.04	961	464
	6	1321	24.9	0.023	1.36	5.22	0.13	8.18	348	226
	7	891	23.6	0.023	1.28	3.57	0.16	4.04	375	135
	8	524	28.7	0.015	3.24	2.09	0.14	1.09	393	287
	9	608	26.4	0.022	1.31	4.73	0.16	1.83	350	181
	10	1396	20.7	0.026	2.15	9.24	0.54	11.49	904	270
	Mean ± SD	886 ± 340	27.1 ± 3.1	0.027 ± 0.012	1.69 ± 0.66	4.53 ± 2.05	0.21 ± 0.15	4.45 ± 3.32	565 ± 229	260 ± 93
Leaf tea	11	670	27.4	0.018	0.93	7.76	0.23	2.40	840	383
	12	505	23.4	0.010	1.41	3.09	0.18	1.00	302	141
	13	277	37.3	0.157	0.84	2.50	ND	0.26	402	141
	14	704	23.6	0.020	0.85	3.08	ND	1.06	373	139
	15	860	24.4	0.032	1.06	3.84	0.45	2.34	439	318
	16	744	21.2	0.033	0.89	3.47	0.38	1.23	366	166
	17	461	23.2	0.177	0.54	1.68	0.11	0.15	282	103
	18	604	27.1	0.013	1.20	3.27	0.25	0.78	465	164
	19	565	33.5	0.033	0.84	4.19	ND	0.60	193	182
	20	648	27.9	0.022	0.94	3.06	0.19	1.04	243	100
	Mean ± SD	604 ± 159	26.0 ± 4.9	0.052 ± 0.06	0.95 ± 0.23	3.59 ± 1.62	0.26 ± 0.12	1.09 ± 0.74	391 ± 175	184 ± 91

ND = no detection level (limit of detection: Co, 0.066 mg/kg).

intake of Mn from three cups of tea provide 62.2% of the daily human requirements for bagged tea and 33.9% for leaf tea [35], whereas for Al the calculated doses are 40% and 19.6% of the daily requirements of the human body, respectively [15]. Because of the homeostatic control that humans maintain over Mn, it is generally not considered to be very toxic when ingested with the diet [11]. Aluminum is generally very poorly absorbed in the gastrointestinal tract, and there is a little indication that Al is acutely toxic for humans via oral exposure [36]. However, several epidemiological studies suggested a positive relationship between the presence of Al in drinking water and Alzheimer's disease [15] as well as other important human pathologies, such as Parkinson's disease and dialysis encephalopathy [13]. Although food is regarded as the major source of exposure to Fe and Ni for the general population [2], the calculated daily intake of Fe from three cups of tea provide

Table 5 – Mean concentration of trace metals in tea infusion (each value is the mean of three samples).

Tea type	Tea sample	Mn	Zn	Cd	Pb	Ni	Co	Cr	Al	Fe
Bagged tea	1	168	7.28	ND	0.055	4.28	ND	0.83	606	4.30
	2	149	8.12	ND	0.194	2.93	ND	0.47	433	4.00
	3	77	8.78	ND	0.041	2.66	ND	0.19	260	2.51
	4	166	7.50	ND	0.245	2.69	ND	0.79	299	3.03
	5	143	5.83	ND	0.133	3.12	ND	0.47	355	4.82
	6	402	9.26	ND	0.060	4.04	ND	1.19	214	2.00
	7	258	9.21	ND	0.237	3.40	ND	0.87	298	1.82
	8	122	8.24	ND	0.396	1.94	ND	0.11	160	5.17
	9	150	9.59	ND	0.087	3.47	ND	0.38	149	4.48
	10	228	5.29	ND	0.267	6.00	ND	1.41	563	2.67
	Mean ± SD	186 ± 89	7.91 ± 1.42	—	0.17 ± 0.13	3.45 ± 1.13	—	0.67 ± 0.41	334 ± 154	3.48 ± 1.23
Leaf tea	11	105	6.56	ND	0.151	5.09	ND	0.52	339	3.46
	12	77	5.98	ND	0.136	1.66	ND	0.17	122	2.43
	13	104	11.14	ND	0.112	1.34	ND	0.15	199	3.91
	14	113	6.82	ND	0.214	1.77	ND	0.32	119	3.73
	15	60	5.45	ND	0.133	1.77	0.210	0.41	147	4.13
	16	136	5.18	ND	0.179	2.64	0.227	0.49	209	2.25
	17	86	7.23	ND	0.069	1.24	ND	0.15	119	2.87
	18	120	7.92	ND	0.113	2.10	0.141	0.29	235	7.18
	19	115	12.14	ND	0.021	1.50	ND	0.40	57	3.51
	20	108	7.21	ND	0.090	1.30	ND	0.23	86	4.02
	Mean ± SD	102 ± 22	7.56 ± 2.26	ND	0.12 ± 0.05	2.04 ± 1.15	—	0.31 ± 0.14	163 ± 81	3.75 ± 1.33

ND = no detection level (limit of detection: Cd, 0.006 mg/kg; Co, 0.066 mg/kg).

Table 6 – The expected calculated intake of elements with tea infusion and average daily intakes.

Element	Content in 1 cup (100 mL) (mg)		Daily intake with tea infusion (mg/d)[a]		Dietary reference intakes (mg/d)
	Bagged tea	Leaf tea	Bagged tea	Leaf tea	
Mn	0.37	0.20	1.12	0.61	1.8–2.3[b]
Zn	0.016	0.015	0.047	0.045	8–11[c]
Pb	0.00034	0.00024	0.0010	0.0007	—
Ni	0.0069	0.0041	0.021	0.012	—
Co	—	0.00039	—	0.0012	—
Cr	0.00134	0.00062	0.0040	0.0019	0.025[b]
Al	0.67	0.33	2.00	0.98	5[d]
Fe	0.0070	0.0075	0.021	0.022	10–18[c]

[a] The amounts were calculated based on the concentration of element in tea infusion and on the assumption that the average consumption of tea beverage for single person is three cups a day with one packet of 2 g (for each).
[b] Institute of Medicine [37].
[c] Jarosz [35].
[d] World Health Organization [16].

only about 0.22% of the daily human requirement for this metal [35]. Similarly, the calculated daily intake of Zn from three cups of tea was very low and provided only 0.60% of the daily requirement [35]. There are no requirements for the safe daily doses of Ni for humans. Ambadekar et al [2] stated that food provide about 0.017 mg of Ni per day. In our study, three cups of bagged tea provided a higher dose of this metal.

Although low daily intakes of most trace metals show that the consumption of black tea is not dangerous for human health, it is essential to have a good tea plant quality control. Moreover, water composition plays an important role in chemical extraction from tea leaves and strongly determines the composition of tea infusion [31]. In the present study, tea infusions were prepared using distilled water. However, tea for consumers will be prepared with water from various sources and hence contains different elemental concentrations, and this may affect elemental concentrations in the tea infusion.

4. Conclusion

The concentrations of trace metals in black tea differed significantly between bagged tea and leaf tea of the same brand. The tea bags contain older tea leaves and low-cost tea materials. For this reason, the concentrations of Pb, Mn, Fe, Ni, Al, and Cr in bagged teas were significantly higher than those in leaf teas. Because of the better extractability of metals from tea materials that had been crushed more thoroughly, the infusions of bagged tea contained higher levels of Mn, Ni, Al, and Cr in relation to the infusions of leaf tea. Generally, the most abundant trace metals in both leaf and bagged teas were Al and Mn.

The results showed that there was a wide variation in the percentage transfer of the examined elements from the dry tea materials to the infusions. The solubility of Ni and Mn was the highest among the elements studied, whereas Fe was insoluble and only a small portion of this trace metal content may leach into infusion. The bagged and leaf teas differed only slightly with respect to metal solubility sequences, which were as follows: Ni > Al > Zn > Mn > Cr > Pb > Fe for bagged tea samples and Ni > Al > Cr > Zn > Mn > Pb > Fe for leaf tea samples.

Although, with respect to the acceptable daily intake of all trace elements in daily dietary standards, the infusions of both bagged and leaf tea samples analyzed in the present study were found to be safe for human consumption, it appears that drinking of tea still provide a significant source of some trace metals.

Conflicts of interest

All authors declare no conflicts of interest.

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REFERENCES

[1] Al-Othman ZA, Yilmaz E, Sumayli, Soylak M. Evaluation of trace metals in tea samples from Jeddah and Jazan, Saudi Arabia by atomic absorption spectrometry. Bull Environ Contam Toxicol 2012;89:1216–9.
[2] Ambadekar SR, Parab S, Bachankar A. Determination of cadmium, copper, nickel, lead in some tea Samples in India. Int J R Pharm Biomed Sci 2012;3:943–6.
[3] Korkmaz Görür FK, Keser R, Akçay N, Dizman S, Okumusoglu NT. Radionuclides and heavy metals concentrations in Turkish market tea. Food Control 2011;22:2065–70.
[4] Matuszak L, Maleszka A. Ocena ekspozycji polskiego konsumenta na ołów pochodzący z herbat. Zarządzanie Fin 2012;10:206–23 [In Polish, English abstract].
[5] Chen G, Yang C, Lee S, Wuc C, Tzen JTC. Catechin content and the degree of its galloylation in oolong tea were inversely correlated with cultivation altitude. J Food Drug Anal 2014;22:303–9.

[6] Szymczycha-Madeja A, Welna M, Pohl P. Elemental analysis of teas and their infusions by spectrometric methods. Trends Anal Chem 2012;35:165–81.
[7] Mehra A, Baker CL. Leaching and bioavailability of aluminium, copper and manganese from tea (*Camellia sinensis*). Food Chem 2007;100:1456–63.
[8] Hicks A. Current status and future development of global tea production and tea products. AU J Technol 2009;12(4): 251–64.
[9] Koblar A, Tavčar G, Ponikvar-Svet M. Fluoride in teas of different types and forms and the exposure of humans to fluoride with tea and diet. Food Chem 2012;130:286–90.
[10] Desideri D, Meli MA, Roselli C, Fuduzi L. Polarized X ray fluorescence spectrometer (EDPXRF) for the determination of essential and non essential elements in tea. Microchem J 2011;98:186–9.
[11] World Health Organization. Manganese in drinking-water, Background document for preparation of WHO guidelines for drinking water quality. Geneva, Switzerland: World Health Organization; 2011.
[12] Gallaher RN, Gallaher K, Marshall AJ, Marshall AC. Mineral analysis of ten types of commercially available tea. J Food Compos Anal 2006;19:53–7.
[13] Karak T, Bhagat RM. Trace elements in tea leaves, made tea and tea infusion: a review. Food Res Int 2010;43:2234–52.
[14] Başgel S, Erdemoğlu SB. Determination of mineral and trace elements in some medicinal herbs and their infusions consumed in Turkey. Sci Total Environ 2006;359:82–9.
[15] World Health Organization. Guidelines for drinking-water quality. Geneva, Switzerland: World Health Organization; 1998.
[16] The Toxicology Department CRCE. Nickel toxicological overview. London: Public Health England; 2009.
[17] Nagpal NK. Technical Report — Water quality guidelines for cobalt. Georgia: Water Protection Section Water, Air and Climate Change Branch Ministry of Water, Land and Air Protection; 2004.
[18] US Department of Health and Human Services. Toxicological profile for chromium. Georgia: Public Health Service, Agency for Toxic Substances and Disease Registry; 2012.
[19] Pękal A, Biesaga M, Pyrzynska K. Trace metals and flavonoids in different types of tea. Food Sci Biotechnol 2013;22(4):925–30.
[20] Dambiec M, Polechońska L, Klink A. Levels of essential and non-essential elements in black teas commercialized in Poland and their transfer to tea infusion. J Food Compos Anal 2013;31:62–6.
[21] Stanisz A. Przystępny kurs statystyki. 1st ed. Kraków: StatSoft Polska; 1998.
[22] Sokal RR, Rohfl FJ. Biometry: the principles and practice of statistics in biological research. 3rd ed. New York: W.H. Freeman; 1995.
[23] StatSoft Inc. STATISTICA (data analysis software system), version 9.0. 2009. www.statsoft.com.
[24] Wong MH, Fung KF, Carr HP. Aluminium and fluoride contents of tea, with emphasis on brick tea and their health implications. Toxicol Lett 2003;137:111–20.
[25] Shu WS, Zhang ZQ, Lan CY, et al. Fluoride and aluminium concentrations of tea plants and tea products from Sichuan Province, PR China. Chemosphere 2003;52:1475–82.
[26] Yemane M, Chandravanshi BS, Wondimu T. Levels of essential and non-essential metals in leaves of the tea plant (*Camellia sinensis* L.) and soil of Wushwush farms. Ethiopia Food Chem 2008;107:1236–43.
[27] Ashraf CW, Mian A. Levels of selected heavy metals in black tea varieties consumed in Saudi Arabia. Bull Environ Contam Toxicol 2008;81:101–4.
[28] Seenivasan S, Manikandan N, Muraleedharan NN, Selvasundaram R. Heavy metal content of black teas from south India. Food Control 2008;19:746–9.
[29] Kumar A, Nair AGC, Reddy AVR, Garg AN. Availability of essential elements in Indian and US tea brands. Food Chem 2005;89:441–8.
[30] Fung KF, Zhang ZQ, Wong JWC, Wong MH. Aluminium and fluoride concentrations of three tea varieties growing at Lantau Island, Hong Kong. Environ Geochem Hlth 2003;25(2):219–32.
[31] Mossion A, Potin-Gautier M, Delerue S, Le Hecho J, Behra P. Effect of water composition on aluminium, calcium and organic carbon extraction in tea infusions. Food Chem 2008;106:1467–75.
[32] Salahinejad M, Aflaki F. Toxic and essential mineral elements content of black tea leaves and their tea infusions consumed in Iran. Biol Trace Elem Res 2010;134:109–17.
[33] AL-Oud SS. Heavy metal contents in tea and herb leaves, Pakistan. J Biol Sci 2003;6:208–12.
[34] Street R, Száková J, Drábek O, Mládková L. The status of micronutrients (Cu, Fe, Mn, Zn) in tea and tea infusions in selected samples imported to the Czech Republic. Czech J Food Sci 2006;24:62–71.
[35] Jarosz M. Normy żywienia dla populacji polskiej-nowelizacja. Warsaw: Instytut Żywności i Żywienia; 2012.
[36] Street R, Drábek O, Száková J, Mládková L. Total content and speciation of aluminium in tea leaves and tea infusion. Food Chem 2007;104:1662–9.
[37] Institute of Medicine, Food and Nutrition Board. Dietary reference intakes (DRIs): recommended dietary allowances and adequate intakes vitamins. Washington, DC: National Academies Press; 2011.